Ammonia emission from individual- and group-housing systems for sows

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Abstract

Given that freedom of movement improves sows' welfare, the implications for the emission of ammonia of keeping sows in groups instead of individually were investigated. Three housing systems were compared: System A, with 64 sows kept individually in feeding stalls with 2.8 m^2 surface area per sow; System B, with 62 group-housed sows, free access stalls with 3.3 m^2 surface area per sow; System C, with 65 group-housed sows, electronic sow feeders and with 3.4 m^2 surface area per sow. The sows in Systems A and B were fed simultaneously twice a day at 7:30 and 15:30 h. In System C the sows were fed sequentially once a day from 15:30 h onwards.

The study was carried out in winter during three one-week periods. Average outdoor temperature was 3.7°C. The average ambient temperatures recorded in the houses were thermoneutral: 19.8°C for System A, 19.2°C for System B and 19.0°C for System C. The average ammonia emission per sow was 0.72, 0.62 and 0.70 g $hour^{-1}$ for the systems A, B and C, respectively. For the systems A, B and C this implied that 23, 20 and 23% of the nitrogen intake was emitted as ammonia nitrogen, respectively. The emission from System B was significantly less ($P<0.05$). The diurnal pattern of the ammonia emissions from Systems A and B were biphasic and were related to feeding times. In System C the diurnal pattern had a more monophasic course related to the feeding time in the afternoon with an additional small peak in the morning after the lights were switched on.

The diurnal pattern of ammonia emission from sow houses was related to the feeding schedule. Under thermoneutral conditions, giving sows a larger area at their disposal – such as with group housing – did not imply an increase in ammonia emission.

Keywords: sows, group housing, individual housing, feeding schedule, electronic sow feeder, ammonia emission, diurnal pattern.

Introduction

Dutch farmers are switching to group housing of sows in anticipation of legislation that will make it illegal from the year 2008 onwards to keep pigs individually. Keeping sows in groups and giving them freedom of movement improves their welfare compared with housing them individually in stalls (Jensen, 1988; Webster, 1994). However, the impact on the ammonia emission from group housing needs to be clarified. Freedom of movement implies that the sows can drop their excrements anywhere. The larger the group, the larger the area that the individual sow has at its disposal and the larger the area fouled with faeces and urine can be. The resulting larger emitting area will increase ammonia emission (Muck & Steenhuis, 1981; Aarnink *et al.*, 1996; Elzing & Monteny, 1997a; Monteny *et al.*, 1998), bringing animal welfare into conflict with environmental issues as ammonia has an acidifying and eutrophying effect on soil and surface water (Heij & Erisman, 1997). These considerations motivated a study of ammonia emission from individually and group-housed sows.

Individually housed sows are fed simultaneously once or twice a day. Group-housed sows are fed simultaneously if all sows have a feeding place, or sequentially if just one or a few feeding places per group are present. So this study included a group-housing system with feeding stalls for simultaneous feeding and a group-housing system with an electronic sow feeder (ESF) for sequential feeding. The study set out to describe the differences in ammonia emission between the housing systems. To understand the cause of possible differences between the systems, the diurnal ammonia emission patterns were compared.

Materials and methods

The experiment was conducted in three different sow-housing systems at the Research Institute for Pig Husbandry in Rosmalen. Figure 1 shows the plans of the systems. In System A, 64 sows were housed individually in stalls and fed simultaneously twice a day. Water was available for one hour during feeding time. In System B, 62 sows were kept in six groups (of 13 sows at the most) with free access stalls and were fed also twice a day. At feeding time they were confined to the stalls for one hour, during 40 minutes of which they had access to water. The rest of the day they could drink *ad libitum* from a nipple in the walking area between the rows of stalls. However, 93% of the water was consumed during feeding time. In System C, 65 sows were kept in five groups (25 sows at the most). Four groups were fed sequentially, using one ESF per group. The feeding station was able to recognize each sow at the entrance and denied it access if it had already eaten its daily ration. Water was available *ad libitum* from a drinking nipple. To facilitate feed intake, 1.1 litre of water was supplied in the feeding station. The remaining group in System C comprised 14 dry sows confined to stalls for 7 to 10 days at the time of mating. During this confinement they were fed once a day when feed was available in the ESFs. On average, the sows in system C visited the ESF once a day and ate the entire ration at one go. All sows in the three systems were fed with the same commercial concentrate, containing 12.6 MJ metabolizable energy (ME) and 139 g crude protein (CP) per kg of feed. Table 1 presents the feeding schedules and summarizes the most important characteristics of the three systems.

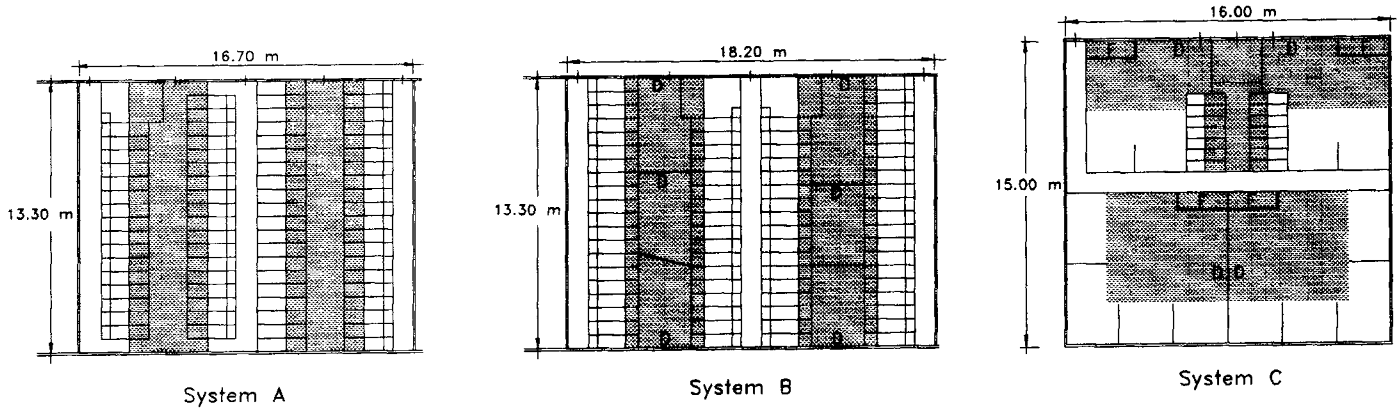

Figure 1. Plans of the housing systems. The shaded parts represent the slatted floor area; solid lines represent stalls and fencing; double solid lines represent walls; drinking places (excluding those in feeding troughs) are indicated with D, feeding stations with F.

Table 1. Characteristics of the three housing systems.

	System A	System B	System C
Feeding schedule			
Order	Simultaneous		Sequential
Time	7:30 and 15:30 h		15:30 h
Intake (kg day^{-1} per sow)	2.8	2.8	2.7
N intake (g day^{-1} per sow)	62	62	60
Water			
Access	Restricted	*Ad libitum*	*Ad libitum*
Consumption (l day^{-1} per sow)	10.7	10.9	9.2
Surface area (m^2)			
Total[1]	178	202	218
Concrete slats	106	52	63
Cast iron slats	–	52	63
Pit	106	104	234
Number of sows	64	62	65
Surface area per sow (m^2)[1]	2.8	3.3	3.4

[1] Excluding feeding alleys of 44, 40 and 23 m^2 in Systems A, B and C, respectively.

The housing systems were equipped with a partially slatted floor and were ventilated mechanically. Systems A and B had 74 stalls; System C was equipped for 84 sows so that during the experiment not all sow places were occupied. The surface area per sow was 2.8, 3.3 and 3.4 m^2 for the Systems A, B and C, respectively, excluding the feeding alleys, which were only accessible to the stockman. Lights were switched on from 7:15 h to 18:00 h. Daylight was able to enter the systems.

The measurements were taken simultaneously in the three systems in the winter of 1996–1997, during three periods of one week: 16–22 September, 9–15 December and 27 January–2 February. Ammonia (NH_3) concentration (mg m^{-3}), ventilation rate (m^3 hour^{-1}), the ambient and outdoor air temperatures (°C), and the water consumption were recorded every 5 minutes. Averages were recorded every half an hour. The concentration of ammonia was measured at the inlet and in the exhaust air in the ventilation shaft with a NO_x analyser. With this method (Van Ouwerkerk, 1993) an air sample was transported to a thermal ammonia converter where NH_3 was converted into NO. The air sample with the less adsorptive gas NO was then transported from the converter to the NO_x analyser (Monitor Labs Nitrogen Oxides Analyser, model 8840) where the NO was measured on the basis of the principle of chemiluminescence (Phillips *et al.*, 1998). The efficiencies of the converters were determined before and after the experiment; they were always higher than 90%. The measured concentrations were corrected for the mean of the efficiencies before and after the experiment. The concentration of ammonia in the exhaust air was corrected for the concentration at the inlet. Ventilation rate was determined with an anemometer with the same diameter as the ventilation shaft. The anemometer had been calibrated in a wind tunnel. The emission was calculated as the product of the corrected NH_3 concentration and the ventilation rate. The ambient inlet and outdoor air temperatures were measured with a sensor (Rotronic®. Proces & Milieu BV, IJzendoorn).

Statistical significance of differences of daily averages between the systems was assessed with analysis of variance and based on the standard errors of differences (SEDs).

Results

The climatic conditions during the study and the ammonia concentrations are summarized in Table 2. The ventilation rate was highest in System B. However, taking into account the number of animals (Table 1) and the volume of the accommodation (965, 1051 and 1044 m^3 for Systems A, B and C, respectively), the frequency at which all the air was replaced was the same as in System C. Although the settings of the climate computer were the same for the three systems, differences – however small – may have occurred due to different tuning of the separate components of the systems (temperature sensors, position of the ventilation flaps etc.). On average, air replacement in System A was 9% less compared with Systems B and C, resulting in a higher ambient temperature.

Figure 2 presents the results of the measurements of the ammonia emission per system and per period. The highest emission (0.77 g $hour^{-1}$ per sow) was recorded in System A during the first period. The lowest (0.56 g $hour^{-1}$ per sow) was recorded in System B during the third period. When periods (n = 3) were considered a factor in the analyses of variance, an interaction was found between system and period ($P<0.05$).

Table 3 presents the mean ammonia emissions for the three housing systems expressed in g $hour^{-1}$ per sow and as the percentage NH_3–N of total N intake per sow. In Systems A and C the mean emissions during the three periods were the same, whether expressed per hour per sow or expressed relative to the N intake. The emission from system B was significantly lower, although the differences were small:

Table 2. Mean temperatures, ventilation rate and NH_3 concentration in Systems A, B and C, with the least significant difference (LSD) between systems (P<0.05).

	System A	System B	System C	LSD
Temperature outdoor air (°C)	3.7	3.7	3.7	–
Temperature inlet air (°C)	14.0	14.0	14.0	–
Temperature ambient air (°C)[1]	19.8 a	19.2 b	19.0 c	0.19
Ventilation rate per sow (m^3 $hour^{-1}$)[1]	52 a	65 b	59 c	3.3
Air replacement ($hour^{-1}$)[1, 2]	3.6 a	3.9 b	3.9 b	0.23
NH_3 concentration (mg m^{-3})[1]	14 a	10 b	12 c	0.8

[1] Means in the same row with no common letter differ significantly ($P<0.05$).

[2] Air replacement is calculated as the quotient of ventilation rate (m^3 $hour^{-1}$) and the volume of the house (m^3).

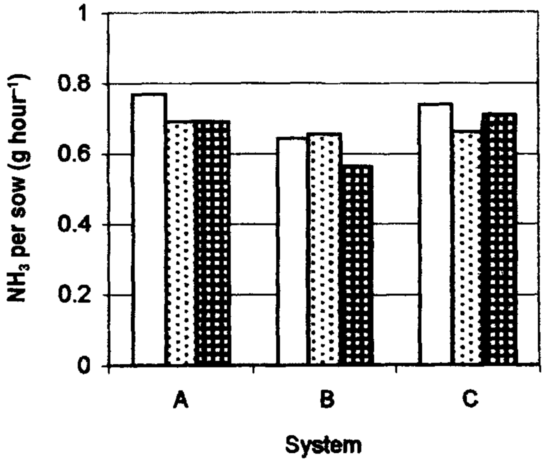

Figure 2. Ammonia emission per sow per system during period 1 (white column), period 2 (dotted column) and period 3 (hatched column).

14% and 11% per sow compared with the Systems A and C, respectively, and 13% considering the N intake.

Figure 3 presents the daily patterns of ammonia emission expressed as the relative difference (%) from the daily average per system. These patterns are based on the means of the observations recorded at half-hour intervals during the three periods (n = 21). The daily variation in ammonia emission was smaller in System C than in Systems A and B: the difference between the minimum and maximum mean emission was 13% for System C, 39% for System A and 47% for System B.

The emissions from Systems A and B, in which the animals were fed simultaneously twice a day, showed a biphasic diurnal pattern, with maxima related to feeding times. The emission from System C showed a broad maximum with a peak just after feeding had started. In system C a slight rise in emission was observed at the start of the day just after the lights were switched on.

Table 3. Ammonia emission per sow from the three housing Systems A, B and C in g hour^{-1} and expressed as NH3–N related to total N intake, and the least significant difference (LSD) with $P<0.05$ (n = 21).

System	Ammonia emission	
	Per sow (g hour^{-1}) [1]	NH_3–N/N intake (%) [1]
A	0.72 a	23 a
B	0.62 b	20 b
C	0.70 a	23 a
LSD (0.05)	0.022	0.735

[1] Means in the same column with no common letter differ significantly ($P<0.05$).

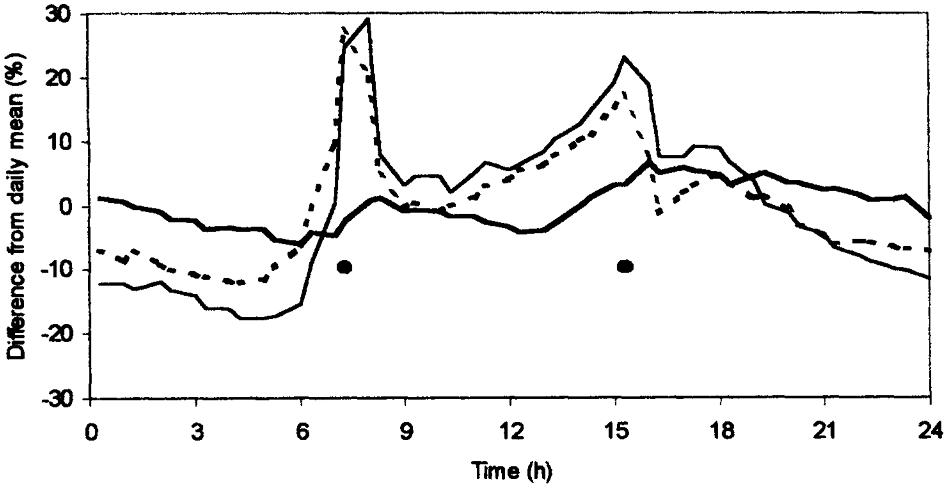

Figure 3. Diurnal pattern of the ammonia emission from System A (broken line), System B (solid line) and System C (bold line). The dots represent feeding times: 07:30 and 15:30 h in systems A and B and 15:30 h in System C.

Discussion

The ammonia emissions from housing Systems A, B and C were within the range presented by Groot Koerkamp *et al.* (1998). In a balance trial, Everts & Dekker (1994) measured a nitrogen excretion during mid pregnancy of 77% of the N intake (61.4 g day^{-1}). Based on this figure, the ammonia emissions in the present study would have been 30% of the excreted N for Systems A and C, and 26% for System B. Whether the ammonia emission per sow was expressed in g hour^{-1} or relative to the N intake (Table 3), the differences between the systems were relatively small (less than 15%). These differences in ammonia emission need not be caused by system-related differences, but may have something to do with the way the systems were actually implemented and with circumstances that cannot or not sufficiently be controlled. In the present study this concerned the surface area of the floor and the pit, the ambient temperature, the ventilation rate, the seasonal effect and the volume of water used. In this study, the feeding schedule (order and times) and the method of water supply (restricted or *ad libitum*) were considered to be system-related differences. Animals fed simultaneously are usually fed twice a day, but with an ESF the sows generally eat the entire ration at one go. The water supply to sows kept individually in stalls was restricted as otherwise the animals would have shown excessive drinking behaviour (Falk, 1971; Stephens *et al.*, 1983; Terlouw *et al.*, 1991; Robert *et al.*, 1993), which could easily have doubled the individual water consumption (Stephens *et al.*, 1983). In agreement with the findings of Van Der Peet-Schwering *et al.* (1997), if kept in groups sows can have *ad libitum* access to water nipples without drinking an excessive amount (Table 1). This means that the actual volume of water used in the present experiment was not related to the system. This volume was smallest in System C. If the water consumption had been the same as in Systems A and B, the urea concentration in the urine from the sows in System C would have been lower (Mroz *et al.*, 1996; Van Der Peet-Schwering, 1997). This would have decreased the ammonia emission from System C, because urea is the main source of ammonia and ammonia emission is linearly related to the urea concentration (Elzing & Monteny, 1997b).

A larger surface area of the pit means a larger emitting area and more emission. A larger surface area of the solid and slatted floor means that a larger area can be fouled with urine and faeces, which also means potentially more emission. If the surface areas had been the same the emission from System C would have been smaller because the surface area of the pit would have been 1.7 m^2 instead of 3.6 m^2 per sow as in Systems A and B (Table 1). However, the ammonia emission from the pit was not expected to be proportionally larger – as might be expected in theory (Elzing & Monteny, 1997a) – because 1.7 m^2 of the slurry pit in System C was underneath solid floors. Here, the air speed was probably very low so that there would have been less emission than from slurry underneath slats (Elzing & Monteny, 1997a, b).

The temperature in System A was highest because air replacement was lowest (Table 2). Correcting for the ambient temperature would decrease the emission from System A compared with the group-housing systems B and C. However, all or part of this correction would be neutralized because the higher temperature in System A was the result of a lower ventilation rate and a lower air speed (Elzing & Monteny, 1997b).

The seasonal effect was not one of temperature as such, because this was the same for the three systems. During hot summer conditions, however, the excretory behaviour of the sows may change. Pigs define areas for resting, feeding and excretory behaviour depending on pen design and temperature (Hafez, 1975; Steiger *et al.*, 1979; Whatson, 1985; Fraser, 1985; Hacker *et al.*, 1994). Under warm summer conditions with temperatures above thermoneutrality, more fouling of the solid flour can occur, which increases ammonia emission (Aarnink *et al.*, 1997). The sows in System A, however, would not be able to adjust their excretory behaviour because their movements were restricted to the stall (1.3 m^2). The sows in System B were able to move around on 25–29 m^2 and in system C on 35–60 m^2, depending on the size of the pens (see Figure 1). This difference in available area means that there will be an interaction between season and housing system, i.e., with increasing temperatures the emission from Systems B and C would increase more than from System A. Consequently, the results of this study cannot be extrapolated to summer conditions with temperatures above thermoneutrality, when fouling of the solid floors can occur.

The above indicates that under thermoneutral conditions and equal circumstances in System C and Systems A and B, emission from System C would have been lower than was actually measured. This, in combination with the relatively small differences in ammonia emission between the systems (Table 3), indicates that under thermoneutral conditions, emission from the individual-housing System A tends to be higher than from the group-housing System C. A likely explanation for this is that if sows have a larger surface area at their disposal they do not necessarily excrete on a larger area. As noted above, pigs define areas for resting, feeding and excretory behaviour. So if their environment permits this hygienic behaviour, it is likely that the emitting area will be reduced. If pigs use a specific, limited excretory area, the urine present on the slats and in the pit will be superseded more frequently by fresh urine. The ammonia in the superseded urine is then no longer in contact with air and consequently less of the dissolved NH_3 will volatilize (Monteny *et al.*, 1998). This effect will be reinforced if urinating behaviour is synchronized in time too. According to Aarnink *et al.* (1996) approximately 75% of the urination of fattening pigs occurs during the day.

The diurnal pattern of the emissions from Systems A and B was biphasic. Several studies describe a similar pattern of activity when sows are fed simultaneously twice a day (Jensen, 1988; Den Hartog *et al.*, 1993; Robert *et al.*, 1993; Krause *et al.*, 1997). The emission from System C showed less distinct peaks. Aarnink & Wagemans (1997) found the same pattern for growing pigs that were fed sequentially, i.e., a small peak in the morning and a bigger one in the afternoon. This pattern fitted ammonia emission as well as activity, making that ammonia emission and activity are correlated. Furthermore, these patterns fitted the food intake pattern presented by De Haer & Merks (1992).

The present study supports the suggestion that the ammonia emission pattern is related to feeding-induced activity of the sows. It indicates the necessity to measure the ammonia emission continuously when comparing different systems with different feeding schedules. It furthermore implies that when efforts are made to develop group-housing systems for sows and reduce ammonia emission, the feeding schedule should be taken into account. From this study it can be concluded that under thermoneutral conditions, giving sows a larger area at their disposal – such as with group housing – does not imply an increase in the ammonia emission per sow.

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